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STRATIGRAPHY OF THE SAINT LOUIS AND WARSAW FORMATIONS IN SOUTHEASTERN IOWA.¹

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INTRODUCTION.

THE stratigraphic relations of the Saint Louis and Warsaw groups in southeastern Iowa have not hitherto been satisfactorily established. The beds succeeding the geodiferous shales of the Keokuk group, first erected into an independent group—the Warsaw—by Hall in 1858, have been included in the Saint Louis group by some writers, while others have referred them to the Keokuk. From a careful survey of the literature it is evident that much of the confusion attending our knowledge of these rocks has arisen from discordant conclusions derived from investigations within the area covered by this paper. As these differences appear to have arisen chiefly from the variable character of the Saint Louis limestone, special attention was given to

¹ Published with the permission of the state geologist of Iowa.

the study of this formation by the author, in the field work of 1893, under the auspices of the Iowa Geological Survey.

EARLIER DESCRIPTIONS.

Owen, 1852.—The first account we have of the geology of this region is that of Owen in 1852.¹ While detailed work was not attempted, his descriptions give evidence of close and accurate observation. He divided the Lower Carboniferous into an upper and a lower series, and named the various subdivisions from lithological or faunal characteristics. No attempt was made to correlate with rocks in other regions of the United States, but in accordance with the prevailing usage of that time he essayed to establish the equivalency of the divisions of the upper series with the members of the Carboniferous section of Yorkshire.

OWEN'S SECTION OF THE LOWER CARBONIFEROUS.

Upper Series.

- f.* Upper concretionary limestone.
- e.* Gritstones.
- d.* Lower concretionary limestone.
- c.* Gritstones.
- b.* Magnesian limestones and shales.
- a.* Geodiferous beds.

Lower Series.

- f.* Archimedes limestones.
- e.* Shell beds.
- d.* Keokuk cherty limestones.
- c.* Encrinital group of Hannibal.
- b.* Encrinital group of Burlington.
- a.* Argillo-calcareous group of Evans Falls.

The gritstones (*e*) of the upper series are said to be marked by the presence of lepidodendron, calamites, and other Carboniferous plants. The sandstones here referred to are, doubtless, the Keosauqua sandstones. Careful search, however, has

¹ OWEN, D.D., Geological Survey, Wis., Ia. and Minn. U. S. Govt., 1852, p. 92.

failed to reveal any plant remains in this deposit, and it is evident that Dr. Owen confounded this sandstone with the basal sandstone of the Coal Measures which is often found occupying depressions eroded in the limestones. Moreover, the study of the region shows that while the succession represented by *c*, *d*, *e*, *f* of the upper series is in a general way correct for particular localities, the members are rather local in their development, and grade more or less into each other. They cannot, therefore, be assigned a position equivalent to the remaining and more general members of the section. The brecciated limestone so often referred to by later writers is included under the lower concretionary limestone (*d*), though very little is said of it.

Hall, 1858.—In the report issued in 1858,¹ the formations are treated in greater detail and a fuller classification is adopted. The geodiferous beds are included in the Keokuk group, while Owen's divisions, *b* and *c* of the upper series, are erected into the Warsaw group, so named from the town on the east bank of the Mississippi, opposite the mouth of the Des Moines River. The remaining members of the series are referred to the Saint Louis group as established by Shumard of the Missouri survey.

Worthen.—In the report made by Worthen on the geology of the Des Moines Valley, the Keosauqua sandstone is evidently identified with the basal sandstone of the Coal Measures. In the report on the geology of Lee county referring to the brecciated limestone he says: "The changes in the lithological characters of this bed, which forms one of its most striking peculiarities, probably led Dr. Owen into the erroneous supposition that there were two distinct beds of concretionary limestone which he has represented in his general section with a bed of sandstone between." Since Dr. Owen's section can be verified locally, as will appear in the sequel, the error is clearly on the other side. Moreover, the magnesian limestones at the base of the Warsaw² group are identified with those occurring on the Des Moines containing *Lithostrotion canadense*, and hence unquestionably belonging to the Saint Louis limestone, a conclusion directly contrary

¹ Geology of Iowa.

² Vol. II., Part. I., p. 193.

to the recognition of the Warsaw as a distinct group. In 1866, *Geology of Illinois*, Vol. I., these formations are held to be related to the Saint Louis and are all included under that group.

White, 1870.—In this report¹ the description of these rocks is still more contradictory. The beds included under the Warsaw group were all referred to the Saint Louis apparently under the erroneous assumption, previously made by Worthen, that the magnesian limestones at the base of the Warsaw are the equivalents of the Lithostrotion beds along the Des Moines. In referring to the character of the Warsaw beds as seen at the typical locality this author says: "The bluish argillaceous shales which so prominently characterize the exposures of this formation at Warsaw are scarcely recognizable in Iowa."² This statement, however, is at variance with Hall's observations, as also our own, as shown by sections given in this paper. Moreover, the sandstone or arenaceous limestone representing the upper member of the original Warsaw is correlated with the Keosauqua sandstone, whereas the former is underneath the brecciated limestone, while the latter is above.

In 1890 the writer³ called attention to the brecciated character for the purpose of suggesting a possible explanation of its origin.

Keyes, 1893.—In Vol. I. of the Iowa Geological Survey⁴ the Warsaw beds are recognized as being closely allied to the Keokuk group faunally, stratigraphically and to a less marked degree lithologically. It is not regarded as of sufficient importance to warrant a separation and is, therefore, included in the Keokuk group, while the discontinuance of the name Warsaw as a title equal in rank to Saint Louis, etc., as advocated by White is sustained. As the removal of the Warsaw beds carried with them their supposed equivalents, the magnesian limestones along the Des Moines, the brecciated limestone is described as constituting the basal member of the group in Iowa.

¹ *Geology of Iowa*, Vol. I.

² *Geology of Iowa*, Vol. I., p. 218.

³ *American Naturalist*, April, 1891.

⁴ KEYES, C. R.: *Geology of Iowa*, 1892, Vol. I. p. 70.

and Coal Measure rocks. They now occur in three areas separated by extensive drift-filled preglacial channels. In Van Buren county no decisive evidence of similar channels has been obtained, but from the great thickness of drift shown by certain well records, and from other indications, there is reason to suspect that Fox River occupies approximately the position of an older stream.

Description of sections.—In the Illinois Geological Report, Vol. I., Worthen has included the Warsaw beds in the Saint Louis group and gives the following section of these rocks at Warsaw :

I. SECTION AT WARSAW.

1. Concretionary brecciated limestone, -	-	-	-	-	30'
2. Arenaceous limestone, -	-	-	-	-	10'
3. Blue argillaceous shales and limestones, -	-	-	-	-	30'
4. Magnesian limestone, -	-	-	-	-	12'
					82'

In this section, Nos. 2, 3 and 4 constitute the Warsaw as established by Hall. At Keokuk the beds between the Geode Shales and the Coal Measures are as follows :

II. SECTION AT KEOKUK.

1. Brecciated limestone; the fragments composed of gray compact limestone, sometimes firmly cemented by similar calcareous material, in other cases with the interstices filled with green clay, -	10'-30'
2. Calcareous sandstone; blue, weathers brown; in some cases quartz grains numerous and coarse, -	8'
3. Blue argillaceous shale with thin variable beds of limestone, the latter subcrystalline and fossiliferous, -	20'
4. Magnesian limestone, brownish gray; in some places coarse subcrystalline, in others fine and of a bluish color; weathers to a yellowish brown, -	4'
62'	

The calcareous sandstone (No. 2) corresponds to No. 2 of the Warsaw section and is quarried to some extent both above and below the city. The limestones of Nos. 3 and 4 are marked by the presence of numerous fossils among which the remains of Bryozoa, notably *Archimedes* and *Fenestella*, are especially abundant. The beds 2, 3 and 4, representing the original Warsaw, have a marked correspondence to the equivalent deposits at Warsaw though considerably reduced in thickness.

Excellent exposures of the Saint Louis limestones occur at various localities on East Sugar Creek :

III. EAST SUGAR CREEK SECTION.

1. Compact light gray limestone; breaks with conchoidal fracture,	-	3'
2. Light brown friable sandstone,	- - - - -	10'
3. Compact fine-grained limestone,	- - - - -	1'
4. Friable calcareous sand,	- - - - -	10'
5. Brecciated limestone; fragments mostly of light-colored compact limestone well cemented by similar calcareous material,	- -	15'
6. Brown magnesian limestone, slightly arenaceous in places; somewhat thick and irregularly bedded; contains lenticular masses of brecciated limestone similar to No. 5,	- - - - -	10'
7. Blue arenaceous shale; includes fragments of chert and siliceous limestone,	- - - - -	6'
		55'

This section occurs on the branch of East Sugar Creek flowing through West Point township. The brecciated limestone is rather coarsely stratified, and appears smooth and waterworn in places. At one point a looser aggregate of the same character occupies what appears to be a channel eroded in the more compact breccia. The lenticular masses occurring near the base of the magnesian beds do not differ essentially from the main mass of the brecciated rock. Near the top of the magnesian beds, however, the lenticular masses are composed, in part, of fragments resembling the brown magnesian limestone itself. At Graner's quarry in the N. W. $\frac{1}{4}$ Sec. 30, T. 68 N., R. 5 W., the beds above the brecciated limestone are represented by sixteen feet of coarse granular limestone, or calcareous sand rock, cross bedded and prominently ripple marked. Beneath the granular limestones there are about eight or ten feet of brecciated limestone followed downward by the same thickness of brown magnesian limestone. A shaft and drill hole penetrated thirty feet of shale below this bed, the upper ten of which was destitute of geodes and apparently represents the Warsaw shales.

One-half mile southwest of the quarry the granular limestones are replaced by fine compact gray limestone containing more or less nodular chert.

At a small quarry one and one-half miles south of Donnellson,

the granular limestones are seen underlain by the brecciated limestone and this by brown magnesian limestone in which *Lithostrotion canadense* was found. This bed is arenaceous in appearance and is locally termed a sandstone.

On the Des Moines River, about a mile below Belfast, the calcareous sandstones represented by No. 2 of the Keokuk and Warsaw sections are twenty to twenty-five feet thick and change locally to blue arenaceous shale. About a half mile east of this locality, a quarry shows the following arrangement:

IV. SECTION AT DEAMUDE'S QUARRY.

1. Clay, yellow above, red below,	-	-	-	-	-	6'
2. Brecciated limestone with pockets of green clay,	-	-	-	-	-	20'
3. Hard blue limestone varying to blue arenaceous shale or shaley sandstone,	-	-	-	-	-	3'
4. Sandstone, blue calcareous, varying locally to arenaceous shale; quarried,	-	-	-	-	-	8'
5. Blue shale,	-	-	-	-	-	15'
						52'

Some closely related exposures on a small creek about a mile west of Belfast are especially instructive. Beginning near the mouth of the stream and following up its course the following sections were taken a quarter of a mile apart. In the intervening spaces, the rocks are not exposed.

V. SECTIONS NEAR BELFAST.

A.

1. Concealed.						
2. Sandstone, blue, weathering brown; somewhat thin bedded and micaceous in places; corresponds to the sandstones below Belfast,	-	-	-	-	-	15'
3. Blue argillaceous shale; no geodes,	-	-	-	-	-	5' +
						20' +

B.

1. Concealed.						
2. Brecciated limestone; light-colored,	-	-	-	-	-	8'
3. Brown magnesian limestone, concretionary, some layers more compact; blue,	-	-	-	-	-	12'
4. An irregular bed of fragmentary limestone and shale, more or less arenaceous,	-	-	-	-	-	6'
5. Blue argillaceous shale, equivalent of No. 3 above,	-	-	-	-	-	1'
						27'

C.

1. Concealed.
 2. Hard, white granular limestone in thin flaggy beds; the lower layers contain grains of quartz, - - - - - 12'
 3. Hard, compact gray limestone, breaks with conchoidal fracture, - 10'
 4. Brown magnesian limestone in thick, somewhat undulating beds, - 10'
-
- 32'

Taking the blue shale as a guide, it is evident that the sandstone in Section A has graded into the magnesian limestones in Section B. In Section C the compact and granular limestones replace the brecciated beds of Section B. The compact limestone is identical with the fragments composing a large part of the brecciated rock and evidently represents an undisturbed portion of the original formation.

Some excellent exposures of the Saint Louis limestones occur near the mouth of Rock Creek:

VI. ROCK CREEK SECTION.

1. Concealed.
 2. Hard, gray compact limestone; contains *Rhynchonella ottumwa*, *Spirifer*, *Keokuk* var. *littoni*, - - - - - 6'
 3. Brown, friable quartzose sandstone, - - - - - 4'
 4. Brecciated limestone, - - - - - 20'
 5. Brown, magnesian concretionary limestone in massive beds; contains *Lithostrotion canadense*, - - - - - 15'
 6. Bed of blue sandy shale, blue grit sandstone, and buff-colored magnesian limestone confusedly mixed together; fragments of chert imbedded in the arenaceous shale, - - - - - 6'
 7. Blue shale interbedded with thin layers of blue fossiliferous limestone, 16'
-
- 61'

The lower bed (No. 7) is referred to the Warsaw shales. The sandstone No. 3 develops locally to twenty and twenty-five feet, while opposite Keosauqua it contains considerable quantities of calcareous matter and, in places, thin ledges and fragments of limestone. The compact limestone above increases to about fifteen feet in thickness near Keosauqua, where it is quarried to some extent. The heavy-bedded concretionary limestones, No. 5, graduate locally into arenaceous limestones and calcareous sandstones. This gradation may be observed in the basal portion in tracing the formation along the bluffs below Keosauqua. At

Price's quarry, on a small branch of Chequest Creek, west of Pittsburg, and on Bear Creek opposite Bentonsport, the sandstones of this horizon are sufficiently developed to furnish a good quarry stone. It consists of blue calcareous sandstone which weathers brown on exposure. In places it is more or less magnesian.

Correlation.—In Van Buren county, the arenaceo-magnesian beds constitute the base of the Saint Louis group. They have a greater development there than in Lee county where they are replaced partially or wholly by the brecciated limestone. They are represented at Keokuk, Warsaw, Sonora (Ill.) and elsewhere by arenaceous beds originally included in the Warsaw group.

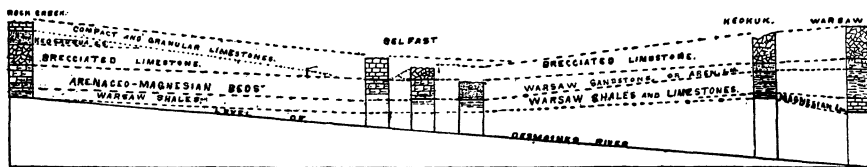


FIG. 2.—Correlation of sections at Warsaw, Keokuk, Belfast and Rock Creek.

The relation of the various beds is shown in the following combined section (Fig. 2) of exposures at Warsaw, Keokuk, Belfast and Rock Creek, while the accompanying table shows the classification here adopted compared with those previously given.

CLASSIFICATION OF THE FORMATIONS OF THE KEOKUK AND SAINT LOUIS GROUPS.

Gordon	FORMATIONS	Hall	White	Keyes
L. C. M.	LOWER COAL MEASURES	L. C. M.	L. C. M.	L. C. M.
Saint Louis	Compact and Granular Limestones (Keosauqua S.S.)	St. Louis	Saint Louis	St. Louis
	Brecciated Limestone	St. Louis		
	Arenaceo-Magnesian Beds	Warsaw		
Keokuk	Warsaw Shales and Limestones	Warsaw	Keokuk	Keokuk
	Geode Shales	Keokuk		
	Keokuk Limestone	Keokuk		

CHARACTERISTICS OF THE FORMATIONS.

The Warsaw shales and limestones.—A consideration of the given sections will show that, at the original locality, the Warsaw group consisted of three members, viz., a bed of magnesian limestone at the base, arenaceous limestone or calcareous sandstone at the top with argillaceous shales, including thin and variable beds of limestone between. Of these the last is the most persistent. The basal division which is twelve feet thick at Warsaw diminishes to three or four feet at Keokuk and is not recognized north of that place. The middle division, however, unchanged in character but greatly diminished in thickness, is recognized at Farmington, Rock Creek and doubtfully at several other localities. The shales and limestones evidently thin out entirely near the north line of Lee county. The formation is prominently characterized by Bryozoa, among which species of *Archimedes*, *Fenestella* and other reticulated forms are conspicuous. With these are associated other forms constituting a somewhat peculiar assemblage of fossils, though on the whole allied to those of the Keokuk group. In the Illinois reports, the peculiarity of the fauna is admitted but is considered of somewhat local development, and is attributed to local conditions of sedimentation rather than to any specific change in the character of the fauna. A somewhat similar assemblage of fossils at Bloomington and Spergen Hill, Indiana, was referred to by Hall as proving the existence of these beds in that state. As later collectors have referred the fossils obtained from these beds to the horizon of the Saint Louis limestone without specific designation of the beds from which they were obtained, new collections must be made before the exact relations of these deposits can be considered established.

Evidently, however, the formation is not of wide extent and probably represents only a comparatively local development of the geode shales into which they grade below. It is suggestive in this connection that the geode shales have their most characteristic development coincident with that of the Warsaw shales and limestones, and both soon lose their distinctive characters

and are traced with difficulty toward the south. The oölitic limestone of Monroe county, Indiana, generally correlated with this formation, has been found to occur in an oblong basin or trough, pointing to local sedimentation.

Arenaceous Limestone of the Warsaw.—The arenaceous member at the top of the original Warsaw group has evidently been the source of much of the confusion in the stratigraphy of this region. At Keokuk, it consists of a blue calcareous sandstone in a single massive bed eight feet thick. It contains large white quartz grains scattered through the finer arenaceous material, the whole being firmly cemented by a large amount of calcareous matter. Locally, the quartz grains become large enough to be called pebbles. With the decrease of the arenaceous element, the rock grades gradually through arenaceous to magnesian limestone. All of these phases may occur together in alternate bands. As a whole, the rock weathers to a characteristic brown from the oxidation of the iron, which takes place more rapidly in the arenaceous parts, giving the rock a banded appearance. At Sonora quarry, four miles below Nauvoo, this formation is well developed. It becomes more shaley toward the north end of the quarry and grades horizontally into brown, cellular magnesian limestone. At the Pontoosac quarries above Niota, Ill., the formation has a maximum development of forty feet at one point in the quarry, rapidly diminishing away from this locality to about fifteen feet. Though having the appearance of a sandstone, and called such, analysis shows it to contain only 7 per cent. of sand, a like proportion of clay, and 60 per cent. carbonate of lime, while the remainder is undetermined, but probably consists principally of magnesian carbonate. Cavities lined with spar and sometimes containing Millerite, are occasionally found in the lower part. In places the arenaceous character is replaced by hard, bluish magnesian limestones. The formation rests upon blue shale of which thirty-three feet was penetrated by drill. The surface of the shale is noticeably irregular and the demarkation between it and the formation above is pronounced. At Deamude's quarry, the character of the formation is very sim-

ilar to that at Pontoosac. The sandstones at the same horizon on Bear and Price's creeks in Van Buren county differ in no important respect from those in the vicinity of the Mississippi.

The brown magnesian limestones.—At numerous places on the Des Moines River and its tributaries above Belfast, brown magnesian concretionary limestone is seen resting upon the Warsaw shales and limestones, though separated from them by a more or less disturbed layer of soft, earthy limestone and arenaceous shale inclosing fragments of chert. The magnesian limestones are disposed in thick undulating beds, and contain considerable concretionary chert. These chert nodules average about one to two inches in diameter, and on the decay of the limestone show a thin layer of green clay lining the cavity inclosing the nodule. The nodules usually contain fossil remains in abundance, generally in a fragmentary condition, though the limestone in which they occur may show very little indication of life. The limestone is usually blue on first removal, but quickly oxidizes to a rusty brown color. In texture, the rock is usually more or less vesicular but varies to a compact somewhat earthy limestone. The latter phase especially characterizes one or two thin ledges. These ledges break down more rapidly on exposure and do not weather brown as in the case of the more vesicular portions. The latter become arenaceous locally, as on the Des Moines below Keosauqua, and on Lick Creek above Kilbourne. At the latter place, the indications of cross bedding are marked. The arenaceous element is observed chiefly in the lower beds. The lowest bed is marked frequently by a large proportion of siliceous matter in irregular masses. These masses are nearly pure white silica and are sometimes disturbed and worn as if by wave action subsequent to consolidation. The greatest thickness of these limestones observed is twenty feet. On Chequest Creek, they are seen to grade upward into a compact, buff-colored limestone known locally as Chequest marble. *On Price's Creek west of Pittsburg, the lower layers grade horizontally into well marked sandstone indistinguishable from the arenaceous limestone of the Warsaw beds at Belfast, Sonora and elsewhere.* The brown limestones are marked

by the presence of the well known and characteristic coral *Lithostrotion canadense*, but this fossil has not been observed in the arenaceous portions. An analysis of the magnesian limestone by Owen¹ shows it to be a nearly pure dolomite, consisting of 56 per cent. carbonate of lime and 37 per cent. carbonate of magnesia. Additional analyses are now being made of these and associated rocks by the Iowa survey.

Compact gray limestones.—Overlying the magnesian limestones at Belfast and on Price's Creek, but usually separated elsewhere by the brecciated formation, is a white or bluish gray compact limestone which breaks with conchoidal fracture, and is usually characterized by brachiopods in greater or less abundance. Among these *Spirifera Keokuk*, var. *littoni*, *Rhynchonella ottumwa*, *Productus tenuicostus* are common. The limestone is a nearly pure carbonate of lime, fine grained and brittle, and corresponds in nearly every particular with the character of the Saint Louis limestone as originally described by Shumard. It is sometimes affected by considerable quantities of nodular chert, in consideration of which Owen termed it the Upper Concretionary limestone. In thickness this formation does not usually exceed fifteen feet.

That portion of these beds which rests directly upon the magnesian limestones on Price's Creek, while in the main similar to the higher strata, differ in being of a darker color, and it is from one of these that the "Chequest marble" is obtained, a block of which was the contribution made by the citizens of Van Buren county to the Washington monument.

Granular limestone.—Associated with the compact limestones in places is a formation of granular white or gray limestone which is remarkable for the pronounced exhibition of cross bedding and ripple marks. These beds evidently represent the limestones from this region which have been described as oölitic, but they are rather of a granular or sandy texture. In some places they contain grains of quartz, though for the most part composed of nearly pure carbonate of lime. Intercalated with the thin flaggy

¹ OWEN, D.D.: Geol. Surv. Wis., Ia. and Minn.

layers of granular limestone, however, one or more thin beds of a purer, fine and compact limestone occur which are especially valuable for the manufacture of lime. The granular limestones are well exposed at Graner's quarry (p. 295) and elsewhere. At Belfast they are seen resting upon the compact limestones, the whole constituting a thickness of twenty-two feet. This formation is sometimes found in small lenticular patches in the brecciated limestone, and in some cases a limited development of true oölitic limestone occurs under similar conditions, but it is not common.

Brecciated limestone.—This constitutes the most generally recognized phase of the Saint Louis group in Iowa. Usually it consists of ten to twenty feet of limestone breccia or conglomerate in which the fragments are of the compact variety noted above, more or less completely cemented by similar calcareous material. In its maximum development it is from 50 to 75 feet thick, the brecciated character in these cases evidently involving all of the preceding formations to the base of the Saint Louis group. In these exposures, as, for example, near the mouth of Reed's Creek in Van Buren county, at Croton, and elsewhere, the lower portion is seen to consist of coarse fragments of the arenaceo-magnesian limestones, and their related sandstones, loosely piled together, and the interstices filled with green clay. The whole takes on a rude stratification, while somewhat persistent but decidedly undulating beds occur at irregular intervals. Upwards the breccia becomes more compact and firmly cemented, and is composed chiefly of the compact white or gray limestones sometimes including the granular type. Away from these areas of greatest disturbance, the lower portion is soon replaced by undisturbed strata of the brown Lithostrotion formation while over this the lighter colored, more compact breccia extends itself in varying thickness. It fails entirely in places, as already noted, and its place is occupied by the compact gray limestones in undisturbed beds. These limestones differ from those which elsewhere rest *upon* the brecciated formation in being of a somewhat darker shade. The fragments of limestone composing the breccia are frequently waterworn, but the wearing has seldom

proceeded very far. In some places it may, with propriety, be called a limestone conglomerate, but from the more or less angular character of the fragments the term breccia is more generally applicable. In some exposures thin lenticular beds of breccia, identical in every respect with the main formation, are intercalated between thick layers of the brown concretionary limestone.

The most prominent fossil found in the brecciated limestone is *Lithostrotion canadense*, though this is not abundant, and occasionally another coral like *L. proliferum*. The latter has also been found in the compact limestones at the horizon of the brecciated formation, where this formation is absent. The brecciated limestone characterizes the Saint Louis throughout nearly the whole of its extent in southeastern Iowa. Except where removed by erosion, and at a few localities (Section V.) where it appears never to have been formed, it constitutes a prominent feature of nearly all the rock exposures in Lee and Van Buren counties. It varies in thickness from five to seventy-five feet, but is usually ten to twenty feet thick.

Keosauqua sandstone.—In the area occupied by the Oxbow bend of the Des Moines, a bed of rather coarse brown more or less friable sandstone is intercalated between the brecciated limestone and the compact gray limestone above. Below Keosauqua it is seen at several places resting upon the brecciated formation with a greater or less thickness of the compact limestone resting upon it. Above that place it is seen in the south bank of the river but little above the level of the water where the basal portion is composed in part of isolated layers of limestone inclosed in the sandstone. Opposite Keosauqua the deposit is much disturbed both in character and stratification, in some cases having a large amount of fine calcareous material mingled with the sand which is very irregularly lithified, while in other cases it contains occasional beds of limestone. The overlying limestone has been removed by erosion in some places, leaving the sandstone at the surface. The area thus exposed, however, is small. In some cases the removal took place prior to the deposition of the Coal Measures so that now these formations rest

directly upon the sandstone. An exposure of this kind occurs on Coates Creek about four miles north of Bonaparte. In thickness the formation varies from a few feet to twenty or twenty-five feet.

The area over which this deposit is recognized is limited. It is not known outside of Van Buren county except at one locality in Lee shown in Section III. (p. 294). In Van Buren county the sandstone appears to be directly related to the Bentonsport arch, evidently lapping up against it in the form of an off-shore deposit and thinning out away from the axis of uplift. In origin and occurrence it is clearly related to the brecciated limestone and is seemingly only a phase of that formation due to local conditions attending deposition. The relations of the various beds is shown in the accompanying hypothetical section from south to north.



FIG. 3.—Section from south to north showing the relations and variations of the Saint Louis limestone: (1) Geode bed (Keokuk). (2) Warsaw shales and limestones (Keokuk). (3) *a.* Arenaceous-magnesian beds, *b.* Brecciated limestone, *c.* Keosauqua sandstone, *d.* White or gray compact and granular limestones. (4) Lower Coal Measures.

UNCONFORMITIES.

Unconformity below the Saint Louis.—It has been shown by White¹ that while the borders of the Kinderhook, Burlington and Keokuk formations recede, showing a gradual withdrawal of the sea to the south, the Saint Louis limestone overlaps these and reaches nearly as far north as does the Kinderhook. “Consequently these beds (Saint Louis) are recognized as resting unconformably upon all the rest of the Lower Carboniferous in Iowa.”²

Hitherto no evidence of unconformity at this horizon has been reported from southeastern Iowa. In the nature of the

¹ *Geology of Iowa*, 1870, Vol. I., p. 226.

² C. R. KEYES has recently found beds with typical Burlington crinoids and other fossils in Keokuk, Marshall and Humboldt counties, proving the extension of these beds nearly to the Minnesota line. Hence the overlap of the Saint Louis is probably not so great as White supposed it to be.

case the evidence would be imperfect since the southern boundary of the state apparently marks the extreme limit to which the sea withdrew at the close of the Keokuk epoch. At several localities, however, we have noted a disturbance in the stratification at the base of the arenaceo-magnesian beds which apparently represents the break referred to. It is usually marked by a confused commingling of arenaceous, shaley and calcareous material inclosing fragments of chert, broken shells, etc. It appears in the Rock Creek section (p. 297) and at several other places in Van Buren county, also on East Sugar Creek in Lee county. The arenaceous deposits of the arenaceo-magnesian beds are also sometimes marked by small quartz pebbles in a more or less calcareous matrix, while the cross bedding in the sandstones indicate proximity to the shore line or at least shoal water.

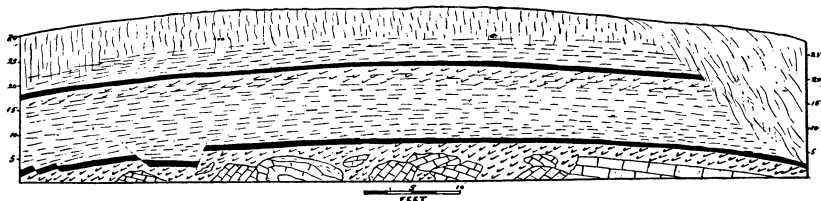


FIG. 4.—Section on Bear Creek, Van Buren county (Sec. 10, T. 68, N. R. 9, W.), showing unconformity of Lower Coal Measure upon Saint Louis limestone.

Moreover, the manner in which the Warsaw shales and limestones below thin out northward offers confirmatory evidence of unconformable relations.

Unconformity above the Saint Louis.—At the close of the Saint Louis epoch the sea again receded, evidently quite rapidly, leaving no enduring evidence of the next succeeding formation (Kaskaskia) which lies 100 miles south of the Iowa boundary. During the Kaskaskia epoch the Iowa region was subjected to extensive erosion, and, on the irregular surface thus formed, the Coal Measure formations were subsequently deposited. Exposures showing this erosion unconformity occur at numerous places in southeastern Iowa. Figure 4 represents an exposure of this character on Bear Creek. The Coal Measure rocks are

here seen resting upon the granular limestones which show various stages of disintegration and decomposition. The clays resting upon the limestones and filling the interstices between the oxidized limestone fragments is evidently the residual product of the decay of the limestones.

About one-half mile west of Rock Creek quarry, the shales of the Coal Measures rest upon the magnesian limestone of the arenaceo-magnesian beds, apparently indicating a channel of erosion at this point (Fig. 5).

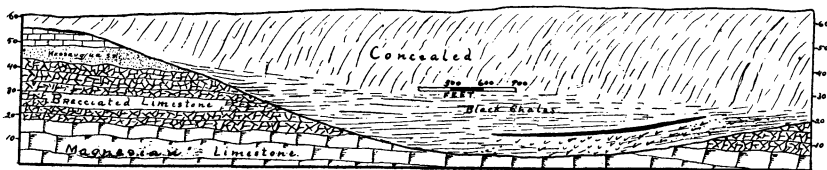


FIG. 5.—Section near the mouth of Rock Creek (Sec. 21, T. 69, N., R. 9, W.) showing eroded surface of the Saint Louis limestone.

One of the best exposures is at the Sonora quarries where the brecciated limestone is entirely cut out by the descent of the Coal Measure rocks (Fig. 6).



FIG. 6.—Section along face of Sonora (Ill.) quarry showing unconformity of Coal Measures upon Saint Louis limestone.

ORIGIN OF THE BRECCIATED CHARACTER OF THE SAINT LOUIS LIMESTONE.

The origin of the brecciated character often prevalent in limestone formations has never been satisfactorily explained. The explanations that have been offered are:

- (1) Wave action upon a rock-bound coast.
- (2) The systematic alternation of vigorous and quiet action

of wind waves taken in connection with tidal oscillation in regions where the sea bottom is subjected to wave action at low tide.

- (3) Wave action especially facilitated by the development of coral reefs.

None of these is sufficient alone to account satisfactorily for the brecciated limestone of the Saint Louis beds, though in each case favored to a certain extent by the character of the formation. The existence of coral reefs contemporaneous with the formation of this deposit, though not clearly proven, is supported by many structural details. In lithological character there is a striking likeness between these deposits and those of modern coral reefs so well described by Dana. Professor Chamberlin has described a similar character of sedimentation in the Niagara limestone of Wisconsin¹ which he ascribes to a like origin. The abundance of life which characterizes the Niagara reefs in Wisconsin, however, does not appear in the brecciated areas of the Saint Louis limestone in Iowa. While corals are present, they are not especially abundant and no coralline masses standing as they grew have been observed.

The alternations sometimes seen between the brecciated and undistributed portions apparently favors the view that the sea bottom suffered an alternation between vigorous and quiet conditions during the time of its deposition. This may be ascribed (1) to oscillations of the earth's crust, or (2) to tidal oscillation where the sea bottom lies just below low tide.

While crustal movements were evidently in progress during the Saint Louis epoch, the acceptance of this view to account for these minor changes would imply a delicacy of adjustment scarcely in harmony with the character of the forces involved. Professor Chamberlin has called attention² to the effect of systematic alternation of wind waves taken in connection with tidal oscillation in accounting for the formation of brecciated limestone. In those areas where the depth of water is such that the sea bottom

¹ *Geology of Wisconsin*, Vol. I., pp. 183-186.

² *Geology of Wisconsin*, Vol. I., p. 168.

is subjected to wave action at low tide it is conceivable that the alternation of forcible and quiet action might constitute an essential factor in the formation of extensive sheets of brecciated limestone. In its advance upon the land at the close of the Keokuk epoch the sea would doubtless encounter irregularities of the surface, some of the elevations reaching nearly or quite to the surface of the water. The Bentonsport arch apparently represents an area of this character. The first deposits would contain more or less arenaceous material derived from the receding shore. Owing to the prevailing calcareous character of the preceding formations, however, the arenaceous material would be insufficient to constitute a widespread sandstone formation. These conclusions are supported by the lithological character of the arenaceo-magnesian beds, the lower portion of which is generally more or less arenaceous and in places decidedly so. The calcareous mud derived by the trituration of the waves upon those parts of the sea bottom within their reach would be deposited in the quiet lagoons or carried out into deeper water to form the fine-grained compact limestones. As the brecciated formation is made up chiefly of fragments of these fine-grained rocks, it is evident that solidification must have taken place very quickly. The presence of lenticular masses of breccia made up of fragments of these fine-grained white or gray limestones interlaid with the massive brown arenaceo-magnesian beds implies that their formation was going on contemporaneously with the sedimentation of the latter beds. Their isolated occurrence, however, as well as their position below the main mass of breccia is not readily explicable unless they represent the thinning out of local masses exposed by tangential erosion. It has been suggested that similar occurrences were due to transportation by shore-ice.¹ The assumption of this agency, however, would preclude the acceptance of coral growth as a factor in the formation of the brecciated limestone, as it implies conditions of temperature inconsistent with the development of reef-building corals.

¹ WALCOTT, C. D.: Bull. Geol. Soc. Am., Vol. V., p. 197.

Dolomitization.—There is a marked difference in lithological character between the arenaceo-magnesian beds and the overlying limestones. The former are decidedly magnesian and in some cases dolomitic, while the latter are almost entirely calcareous. Where the brecciated bed is absent there appears to be a gradation between the two. The explanations which have been proposed to account for dolomitization are:

- (1) Chemical precipitation or sedimentation.
- (2) Leaching of carbonate of lime from a magnesian limestone subsequent to solidification.
- (3) Replacement of some of the lime by magnesia subsequent to solidification.¹

From the record of observations it seems probable that all of these processes have taken place. With regard to the first view it has been shown by Dana² that while "corals themselves contain very little carbonate of magnesia, magnesia is largely present in some specimens of the rock." The coral sand and some of the compact limestones, however, are said to have very little or no magnesia. The conclusion is drawn that the introduction of the magnesian element has taken place (1) in sea waters at the ordinary temperature and (2) without the aid of any mineral waters except the ocean. The change is thought to have taken place in contracting and evaporating lagoons in which the magnesian and other salts of the ocean were in a concentrated state. That dolomite is essentially a littoral deposit has been advocated by Calvin,³ while Geikie says that while some dolomites may have been formed by chemical precipitation in inland lakes and seas, others may have been formed by the action of magnesian salts of sea water upon organic limestones already formed.⁴ The relations of the magnesian and compact limestones in southeastern Iowa favor the conclusion that they were formed under essentially the same conditions. As the magnesian character

¹ HOPKINS, T. C.: *Geol. Sur., Ark.*, 1890, Vol. IV., p. 38.

² *Corals and Coral Islands*, p. 393.

³ *American Geologist*, Vol. I., p. 30, and Vol. II., p. 36.

⁴ *Text-book of Geology*, p. 296.

appears more pronounced in areas affected by brecciation and has not been noted as far south as St. Louis, there is a strong presumption that the conditions attending the formation of brecciated limestone exercised a controlling influence in effecting the transformation of the rock. The limestone of the Niagara reefs of Wisconsin are dolomitic, as indeed are nearly all those found in that state.¹ The available evidence, therefore, is apparently in favor of Calvin's conclusion that dolomites are essentially off-shore products.

C. H. GORDON.

¹ Geology of Wisconsin, Vol. I., p. 303.